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Opportunities and Barriers for Sustainable International Bioenergy Trade

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Abstract

Trade of biomass and bioenergy (biotrade) can provide a stable and reliable situation for sustainable production of biomass fuels, become a source of additional income and increased employment (e.g., for rural communities), and may contribute to the sustainable management of natural resources. For importers, biotrade may assist to fulfil greenhouse gas emission reduction targets in a cost-effective manner, diversify their fuel mix, and lead to more sustainable energy production. Stimulated by the renewable energy policies in several countries, rising oil prices, and a wish for diversification of supply, in most Task 40 Member Countries growth rates of 10-20% or more per year have been observed in international trade of biomass and bioenergy.

However, a multitude of different barriers currently exist, hampering the development of international bioenergy trade. These include economic, technical, logistical, ecological, social, cognitive, legal, and trade barriers, lack of clear international accounting rules and statistics, and issues regarding land availability, deforestation, energy balances, potential conflicts with food production, and local use versus international trade.

Background and Rationale

A reliable supply of and steady demand for bioenergy are vital for developing market activities in this area. Given the expectations for a high bioenergy demand on a global scale and by many nations, the pressure on the available biomass resources will increase. Without the development of biomass resources (e.g., through energy crops and better use of agro-forestry residues) and a well functioning biomass market to assure a reliable, sustainable and lasting supply, those ambitions may not be achieved. The development of international markets for bioenergy may become an essential driver to develop bioenergy potentials, which are currently under-utilised in many regions of the world. This is true for residues and for dedicated biomass production (through energy crops or multifunctional systems such as agro-forestry). The opportunity to export biomass-derived commodities for the world's energy market can provide a reliable demand for rural communities, thus creating important socio-economic development incentives and market access. Trade in biomass energy carriers (biotrade) may also enable a more efficient use of materials.

It is essential that this growth in biomass production and trade proceeds in a sustainable manner. This is of special importance for biomass as sustainability is one of the main reasons for developing renewable energy sources.

Objectives

Task 40 'Sustainable International Bioenergy Trade: Securing Supply and Demand', started in 2004 and currently has 10 participating countries, plus the FAO as an affiliated international body. In addition, joint activities have been organised with other institutions, e.g., the World Bank, EUBIONET II and other IEA Bioenergy Tasks. A key element of the work programme is monitoring the rapidly growing international bioenergy trade in solids, liquid fuels, and power while simultaneously evaluating opportunities and barriers for the development of a sound international market. From 2004 to 2006, Task 40 has produced a number of reports and jointly organised a number of workshops (see www.bioenergytrade.org). This report summarises the main results and the input from all Task 40 participants, and addresses bioenergy trade from the point-of-view of these participants. It highlights the main issues currently hampering development of the international trade in biomass.

While this paper deals with bioenergy trade barriers and opportunities in general, a number of deliverables under the work programme of Task 40 specifically emphasise the sustainability aspects of biomass supply and demand. In some of the participating countries the support measures for bioenergy are formally linked to sustainability and hence this issue receives particular attention.

Furthermore, bioenergy trade requires a good understanding of supply and demand issues. Barriers to both supply and demand can hamper international trade but it is beyond the scope of this paper to present an exhaustive overview of all barriers related to biomass production, trade, and use. Where appropriate, we have included references for more information.

It is also important to note that the field of international biotrade is developing rapidly, and thus frequent reviews of barriers and opportunities may be needed (e.g., bi-annually). The topics described in this paper reflect the situation in 2006.

Opportunities

Many countries have both a large technical agricultural and forestry residue potential and a large potential for dedicated energy plantations forming the base for efficient production of biofuels such as pellets (Bradley, 2006), or charcoal from energy plantations or ethanol from sugarcane (Walter et al., 2006). Given the availability of land and relatively low costs of labour in many developing countries, biomass production costs can be low and offer an opportunity for exporting biomass-based energy carriers to developed countries. The export of biomass-derived fuels for the world's energy markets can provide a reliable demand for fuel from rural communities, particularly in many developing countries; this can create an important incentive and access to the market in many areas of the world. However, availability of resources per se is not enough as there are many other factors that need to be taken into account, e.g., accessibility, quality, etc.

In the past decade such trade flows have been increasing rapidly. Many trade flows are between neighbouring countries, but increasingly, long-distance trade is also occurring. Examples are the export of ethanol from Brazil to Japan and the EU, palm kernel shells (a residue of the palm oil production process) from Malaysia to the Netherlands, and wood pellets from Canada, Eastern Europe, and Brazil to Sweden, Belgium, the Netherlands, and the UK.

These trade flows may offer multiple benefits for both exporting and importing countries. For example, exporting countries may gain a source of additional income and an increase in employment. Also, sound biomass production can contribute to the sustainable management of natural resources. Importing countries may be able to meet their greenhouse gas (GHG) emission reduction targets and diversify their fuel mix and thus contribute to greater energy security, a major driving force in most OECD/IEA countries. Today, bioenergy is cost-efficient, in some cases even in direct comparison with oil (e.g., for heating purposes).

For market participants such as utilities, companies providing transportation fuels, as well as those involved in biomass production and supply (such as forestry companies), good understanding, clear criteria, and identification of promising possibilities are of key interest. Investments in infrastructure and conversion capacity rely the on minimisation of risk of supply disruptions in volume, quality, and price.

Biomass energy in general, and international biomass trade in particular, offers many opportunities. These are described in detail in the various country reports published by Task 40 (e.g., Bradley, 2006; Heinimö and Alakangas, 2006; Junginger et al., 2006; Walter et al., 2006; see also www.bioenergytrade.org for more country reports). They are not, however, the main concern of this report. For an overview of the global theoretical potential of biomass, see Smeets et al., 2004; for a general discussion of the potential of biomass energy, see Turkenburg et al., 2000.

Inventory of Barriers

Based on Task 40 results, a literature review, and interviews, a number of potential barrier categories have been identified. These barriers may vary greatly in terms of scope, relevance for exporting and importing countries, and how stakeholders perceive them. A summary of the main barriers is given below. At the same time, it must be emphasised that, depending on the situation, these barriers can also be opportunities, and thus some positive examples are also included.

The categorisation of the barriers is to some extent arbitrary. Some of the issues discussed under the various headings are complex and encompass elements of several barriers, e.g., logistical barriers indirectly cause economic barriers.

Economic barriers

One of the principal barriers to the use of biomass energy in general is the competition with fossil fuel on a direct production cost basis (i.e., excluding externalities). For example, the market price in 2004-2005 for biomass pellets in the Netherlands was about 7 to 7.5/GJ (van Sambeek et al., 2004), while the cost of coal in 2005 was about 2/GJ. On the other hand, current production costs lie between US$0.7/GJ (free on board in the Amazon) and US$1.7/GJ (transported in the Southeast) in Brazil (Walter et al., 2006)[1]. Thus, the high prices seem to be caused by a strongly increasing demand over recent years, while cheap raw materials at favourable prices are no longer available in abundance and cannot support production increase at the same pace as the development of demand.

In order to promote bioenergy many developed and some developing countries have stimulated the development and use of biomass for electricity, heat and transportation by the introduction of measures such as governmental RD&D programmes, tax cuts and exemptions, investment subsidies, feed-in tariffs for renewable electricity, mandatory blending for biofuels, or biofuel quotas. However, an often-heard criticism from the industry is that these measures may not be sufficient (e.g., no mandatory target for the EU-25 Biofuels Directive). In addition, they are mostly temporary and tend to change frequently. This discourages long-term investments, as they are considered too risky. On the other hand, thanks to the EU Biofuels Directive, the EU production of biofuels more than tripled within the past 2 years and continues to grow. Thus, the European Commission argues that the policies adopted have attracted investment in new production facilities (K. Maniatis, pers. comm.).

Studies have indicated huge potential for biomass supply from some regions, such as Canada and Brazil. The limiting factor in biomass supply often is not the amount available, but the investment required to gather and pre-treat or densify the biomass to make transportation economic. Capital for investment in these regions may be limited, or investment may be deemed too risky until markets show some long-term stability and growth. Options for fully developing these resources include long-

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1. It is, however, not clear whether these prices include capital costs, and probably the raw material is available for free.

term contracts for biomass at prices that ensure economic return for the local investor, or integrating supply operations with demand, whereby biomass consumers in one region invest in plant in the supplying region.

Due to the often small size of bioenergy markets and the fact that biomass by-products are a relatively new commodity in many countries, markets can be immature and unstable, as in the case of the wood pellet market. During the winter of 2005-2006, this market was very volatile due mostly to supply shortages, caused by much higher demand from European households (who were replacing their expensive fossil fuels with wood pellets), higher demand from power companies, and difficulties in the supply of pellets due to a long period of cold weather. All these factors meant that suppliers did not manage to meet the unforeseen demand. The efforts of some market areas to solve the lack of supply were futile because some of the new producing parties tended not to honour contracts but sold their shipments to the highest bidder (P-P. Schouwenberg, pers. comm.). This is one example that shows the immaturity of this market.

Unstable markets make it difficult to sign long-term, high-volume contracts as this is seen as too risky. Also, with no harmonised support policy (e.g., on a EU level), new national incentives (and associated demand for bioenergy) may distort the market and shift supply to other countries within a short timeframe (Faber et al., 2005). Due to increasing international competition, Dutch traders expect a growing demand for cheap biomass fuel streams in the mid-term (5-10 years) in developed countries, but also in developing countries because of the expected rise in local demand (Junginger et al., 2006).

Due to the small volumes, biomass fuel trade is so far completely bilateral, i.e., direct agreements between buyer and seller. A few biomass exchange websites have emerged over the past year, but traded volumes remain low.

In summary, while the strong increase in overall biomass demand is a positive development in itself, the market is hampered at present by many factors such as its dependence on (short-term) policy support measures and typical problems of emerging markets such as small bilateral volumes, a lack of market transparency, etc.

Technical barriers

A general problem of some biomass types is variable physical properties (e.g., low density and bulky nature) and chemical properties, such as high ash and moisture content, and nitrogen, sulphur, or chlorine content. These properties make biomass difficult and expensive to transport, and often unsuitable for direct use, say for co-firing with coal or natural gas power plants. Power producers are generally reluctant to experiment with new biomass fuel streams, e.g., bagasse or rice husks. As shipments within these streams often fail to provide the required physical and chemical properties, power producers are afraid to damage their installations (designed for fossil fuels), especially the boilers. While technology is available to deal with the fuels (e.g., different types of fluidised bed boilers), it may take several years or even decades before the old capacity is replaced (Heinimö and Alakangas, 2006). In the longer term, the limited ability to use different fuels may lead to a restricted availability of biomass fuels (Junginger et al., 2006). This is a particularly important issue as many European coal-fired power plants need to be modernised or shut down in the next 5 to 10 years.

Logistical barriers

Related to technical barriers are logistical barriers. One of these problems is a general lack of technically mature pre-treatment technologies for compacting biomass at low cost to facilitate transportation, although this is fortunately improving. Densification technology has improved significantly recently (e.g., for pellets) although this technology is only suitable for certain biomass types. Also, the final density per cubic metre is still far less than oil for example, given the nature of biomass. Pyrolysis or torrefaction may be a possible pre-treatment option, but still needs to be proven on a commercial scale. In the case of the import of liquid biofuels (e.g., ethanol, vegetable oils, biodiesel), this is not an issue, as the energy density of these biofuels is relatively high.

When setting up biomass fuel supply chains, for large-scale biomass systems, logistics play a pivotal part. Various studies have shown that long-distance international transport by ship is feasible in terms of energy use and transportation costs (Hamelinck, 2004) but availability of suitable vessels and meteorological conditions (e.g., winter time in Scandinavia and Russia) need to be considered.

However, local transportation by truck in countries involved in both exporting and importing of biomass may be a high cost factor, which can influence the overall energy balance and total biomass costs (Batidzirai et al., 2006; Hamelinck, 2004). For example, in Brazil, new sugarcane plantations are considered in the Centre-West, but the cost of transport and lack of infrastructure can be a serious constraint. Harbour and terminal suitability to handle large biomass streams can also hinder the import and export of biomass to certain regions. The most favourable situation is when the end user has a facility close to the harbour and so avoids additional transport by trucks.

The lack of significant volumes of biomass can also hamper logistics. In order to achieve low costs, large volumes need to be shipped on a regular basis. Only if this can be assured, will there be forthcoming investment on the supply side (e.g., new biomass pellet factories) and this will reduce costs significantly. The bulky nature of biomass fuels and the relatively low value per unit would restrict availability of suitable areas for handling these fuels in busy ports. On the other hand, this bulky nature in combination with a high demand for specific biomass streams means that the present capacity (including storage, handling equipment, etc.) of some harbours (e.g., Stockholm, Gothenburg, Immingham, several harbours in the Baltic States) is fully utilised. A further increase in biomass handling would require specific investment.

International trade barriers

As with other traded goods, several forms of biomass can face technical trade barriers. As some biomass forms have been traded only recently, so far no technical specifications for biomass and no specific biomass import regulations exist. This can be a major hindrance to trading. For example, in the EU most residues containing traces of starches are considered potential animal fodder, and thus subject to EU import levies. For example, rice residues containing 0-35% starch are levied E44/ton (about E3.1/GJ) (Junginger et al., 2006). For denaturised ethanol of 80% and above, the import levy is E102/m^3 (about E4.9/GJ), representing substantial additional costs. Brazil is planning to increase ethanol production drastically over the next 8 years, and to start up biodiesel production from soy beans, palm oil, etc., although only a fraction of both biofuels will be exported and the rest will be used domestically. Brazil could, in theory, export more ethanol than is scheduled so far. A major constraint is that countries with large markets (USA, Japan, and the EU) are completely or partially closed due to trade barriers. The USA applies *ad valorem* duties of 2.5% for imports from most-favoured-nations (MFN) and 20% for imports from other countries. Japan applies *ad valorem* duties of 27% - MFN treatment. At present, these duties represent a significant barrier to trade, influencing the competitiveness of foreign imports. It is important to ensure that treatment takes into consideration the status of the exporting countries, to account for their level of development and potential for export. Finally, it is important to bear in mind that some technical trade barriers can, in fact, be imposed to constrain imports and to protect local producers.

Another issue connected with international trade is transport tariffs. In recent years, general transport tariffs have increased quite significantly, e.g., wood pellets to the Netherlands were on average E1.75/GJ (on a total cost of E7-7.5/GJ) in 2004 (van Sambeek et al., 2004). This was caused partly by the high demand for transportation from South-east Asia, but demonstrates the dependence of biotrade on low transportation tariffs.

In addition, the risk of contamination of imported biomass with pathogens or pests (e.g., insects, fungi) is another important limiting factor in international trade. For example, undebarked untreated roundwood and chips from outside Europe are (with a few exceptions) not allowed and are inspected thoroughly for import into the EU (Heinimö and Alakangas, 2006). Similarly, agricultural residues which could be used both as fodder and biomass for energy, may currently be denied entry if they do not meet certain fodder requirements. However, it is important to bear in mind that these limitations are not exclusive to bioenergy, and that they are in place to protect public and animal health.

A potential future trade barrier may be the biotechnology issue. Many countries (mainly in the EU) are highly opposed to import products where biotechnology was used (Cartagena Protocol on Biosafety). However, in short-rotation plantations and energy crops, genetic modifications, e.g., for increasing the yield or the water content, are beneficial for bringing down production costs. This may, for example, be relevant for ethanol from genetically modified corn or sugarcane.

Ecological barriers[2]

Large-scale plantations dedicated to energy from biomass may pose various ecological and environmental issues that cannot be ignored, e.g., monocultures and associated potential loss of biodiversity, soil erosion, fresh water use, nutrient leaching, and pollution from chemicals (Lewandowski and Faaij, 2004; Smeets et. al., 2005). For example, the cultivation of soy beans in Brazil and palm oil in Indonesia and Malaysia for food and fodder has been strongly criticised by various environmental NGOs because of the negative social and environmental effects, e.g., the violation of land property rights of small farmers, or the additional pressure on land and on valuable ecosystems such as rain forests[3]. Use of soy bean oil and palm oil as feedstock for biofuels would contribute to these effects. However, studies have shown that for dedicated perennial, woody, energy crop plantations in general these problems can be less serious than for the currently common crops for food or fodder production. If designed and managed wisely, biomass plantations can be multi-functional and generate local environmental benefits. For example, willow plantations in Sweden may be used for soil carbon accumulation, increased soil fertility, reduced nutrient leaching, shelter belts for the prevention of soil erosion, plantations for the removal of cadmium from contaminated arable land (phytoextraction), and vegetation filters for the treatment of nutrient-rich, polluted water (Börjesson and Berndes, 2006). Short-rotation woody crops (SRC) in general require very few inputs of herbicides and pesticides. Rich et al., (2001) reported SRC plantations were generally better for a wide variety of wildlife than existing adjacent farmland around the ARBRE project area (UK). When established on agricultural land the usual result is an increase in bio-diversity, i.e., no significant displacement of species and in some cases an actual increase of species occurred. SRC is generally regarded as environmentally friendly and most environmental groups view the technology favourably. Also, in the UK large-scale SRC monoculture is unlikely given the nature of land tenure. Rather, the most likely scenario may be a large number of small plots scattered over large areas.

Social barriers[2]

Also linked to the potential large-scale energy plantations are the social implications, e.g., the effect on the quality of employment (which may increase, or decrease, depending on the level of mechanisation, local conditions, etc.), potential use of child labour, education, and access to health care (Lewandowski and Faaij, 2004; Douglas et al., 2004). However, such implications will reflect prevailing situations and would not, necessarily, be better or worse than for any other similar activity. One example is the agricultural sector in Brazil, where the level of social

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2. Some Task participants see this as a land use issue. Responsibility for land use (changes) lies with many more actors, and is clearly not the sole responsibility of bioenergy trade alone. Also, the ecological and social barriers only have indirect influence on trade.

3. Furthermore, a well-known feedstock for ethanol production is sugarcane. In a recent report from Task 40 participants (Smeets et al., 2006) it was shown that current ethanol production from sugarcane in Sao Paulo does not pose any major ecological problems, nor does it directly threaten the Amazon rain forests.

benefits and child labour are still important issues but they have significantly improved over the period 1992-2004. Macedo, (2005, see chapter 12), gives an account of the positive contributions of the sugarcane and ethanol industry on job creation and income. Further examples of social benefits are highlighted by Woods and Hall (1994) for developing countries, and Perlack et. al., (1995), on woody biomass plantations.

Competition between and integration of biomass for energy applications and for other end uses.

Various types of biomass can be utilised for end-uses other than energy, e.g., as raw material for the pulp and paper industry, as raw material for the (chemical) industry (e.g., tall oil or ethanol), as animal fodder (e.g., straw), or for human consumption (e.g., ethanol or palm oil). This competition can be directly for biomass, but is also often focused on land availability.

Throughout human history biomass in all its forms has been the most important source of all our basic needs, often summarised as the six 'Fs': Food, Feed, Fuel, Feedstock, Fibre, and Fertiliser. Biomass products are also frequently a source of a seventh 'F' - Finance. Until the early 19th century biomass was the main source of energy for industrial countries and, indeed, it continues to provide the bulk of energy for many developing countries. Food versus fuel is a very old issue that is frequently brought up despite the fact that a large number of studies have demonstrated that land availability is not the real problem (Partners 4 Africa, 2005). While theoretically large areas of (abandoned/degraded) crop land are available for biomass cultivation, biomass production costs on such land are generally higher due to lower yields and accessibility difficulties. Deforested areas may have more productive soil, but these sites are generally considered unsustainable in the long term. Food security, i.e., production and access to food, would probably not be affected by large energy plantations if proper management and policies were put in place. However, in practice food availability is not the problem, but the lack of purchasing power of the poorer strata of the population. A new element to take into account is climatic change, which introduces a high degree of uncertainty.

As mentioned above, next to competition with food, there also may be competition with other applications, such as fodder. If there was a large increase in demand for energy, say from agricultural residues, scarcity of fodder products could occur, leading to price increases. In the Netherlands, the fodder industry sees the feed-in tariff for electricity from biomass as an indirect subsidy for agro-residues (Junginger et. al., 2006); on the other hand, the use of fodder is also subsidised. Similar arguments have been voiced by the European pulp and paper industry, which fears the increasing competition from strong promotion and subsidies for renewable energy sources in the EU. Increasing competition for wood will increase the price and lower the supply of the raw material for the forest industry, decreasing the competitiveness of the European pulp and paper industry (CEPI, 2006). Wood use for forest products usually gives greater added value and creates more jobs than the direct use of wood products for energy production (CEPI, 2003). Furthermore, there is a large potential market for bio-products and the use of woody feedstocks to replace fossil-based feedstocks – an issue we do not further address here.

Methodological barriers – lack of clear international accounting rules.

Before large-scale international trade of bioenergy can be implemented, clear rules and standards need to be established, e.g., who is entitled to the CO_2 credits. A related issue concerns the methodology that should be used to evaluate the avoided emissions, considering the fuel life-cycle. As these avoided emissions typically depend strongly on the chosen reference system, it is debatable whether the same methodology could be applied to all biomass sources.

Another issue is the indirect import of biomass for energy (processed biomass). Biomass trade can be considered as a direct trade of fuels and as indirect flows of raw materials that end up as fuels in energy production after the production process of the main product. For example, in Finland, the biggest international biomass trade volume is indirect trade of raw wood (including roundwood and pulp chips). Almost half of these imports end up as by-products (e.g., bark, sawdust, and black liquor) used for energy production (Heinimö and Alakangas, 2006).

Legal (national) barriers

International environmental laws may limit biomass for energy. For example, in the Netherlands, four out of five major biomass power producers consider obtaining emission permits to be one of the major obstacles to further deployment of various biomass streams for electricity production. The main problem is that Dutch emission standards are not entirely consistent with EU emission standards. In several cases in 2003 and 2004, permits given by local authorities have been declared invalid by Dutch courts (Junginger et al., 2006). While these barriers only indirectly influence international bioenergy trade, they may cause a significant reduction of potential biomass import volumes.

Lack of information dissemination

Both the benefits of sustainable biomass energy in general and specifically the need for international biomass trade are still largely unknown to many stakeholders such as industrial parties, policy makers, NGOs, and the general public. More active dissemination of information by IEA Bioenergy, various UN institutions, national governments, and other organisations is required.

Broader Issues to be Considered in Relation to Biomass Trade

Energy balances and local use *versus* international trade

The overall energy balance of biomass and biofuels use needs to be positive, although this is not always clear cut. Energy balances have improved considerably in the last decade as productivity has increased with lower inputs, as in the case of ethanol from sugar cane in Brazil (Macedo, 2005). Similarly, some oil crops such as palm oil, dende, and macaúba can deliver biodiesel with relatively high energy output/input ratios (Horta Nogueira, 2005). Related to energy balances are GHG balances of biofuels[4]. As shown in a report published by the IEA (2004), the current production of ethanol from wheat and sugar beet or biodiesel from rape seed (as is currently the main practice within the EU) achieves lower GHG emission reductions (typically in the range of 20-60%) than ethanol from sugarcane (80-90%) (Quirin et. al., 2004). Development of such first-generation biofuels with mediocre energy and GHG balances on a large-scale is often driven by additional considerations such as fuel security, and employment in the agricultural sector, but could be considered unsustainable by some in the longer term[5]. For example, import of ethanol produced from sugarcane would generally show better energy and GHG balances, but these balances are somewhat worsened by long-distance transport – especially when including substantial transportation by truck.

Connected to this issue is the question whether biofuels should be used preferably locally or traded internationally. While many developing countries have a low energy consumption compared to developed countries, their energy demand is increasing rapidly. Should biomass for energy be utilised locally or exported; should market forces have the last say? For example, Finland currently exports to other EU countries large volumes of pellets which could also be utilised domestically. The main drivers are higher incentives paid for electricity from pellets in other European countries.

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[4] GHG emissions are often coupled to energy inputs during the production of biofuels, e.g. diesel fuel for agricultural machinery. However, emissions of other GHG gases such as methane or nitrous oxide during biomass cultivation also influence GHG balance, but not the energy balance of biofuels.

[5] For example, in the Netherlands, a commission consisting of various stakeholders from government, industry, and NGOs decided that minimum sustainability criteria for biomass should achieve 30% GHG emission reductions, though by 2011 this level should be increased to 50% (Cramer, et. al., 2006).

It can be expected that countries that have greater difficulties in meeting commitments (Kyoto, green policies, etc.) will introduce stronger incentives. From an energy efficiency point of view, it would be more rational to use the biomass primarily locally, and export only the excess[6]. However, the actual energy balances and CO_2 emission reductions also depend strongly on the reference energy systems in both the exporting and importing countries. Furthermore, it should be borne in mind that international competition will force domestic producers to be more competitive.

For more information about Task 40, visit www.bioenergytrade.org

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[6] *Some Task participants do not fully support this assumption. Also, they emphasise that we trade food products all over the world, and that rules for biomass should not be too ambitious – environmental and other principles should be applied equally across sectors.*

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UPDATE 33

"This article was produced by the Implementing Agreement on Bioenergy, which forms part of a programme of international energy technology collaboration undertaken under the auspices of the International Energy Agency."

Mechanical Biological Treatment of Municipal Solid Waste

This Technology Report from Task 36 was prepared for ExCo58 in Sweden in October 2006 by Nicole Jaitner and Jim Poll

Abstract

The IEA Bioenergy Agreement is set up to examine and develop bioenergy solutions. One potential source of energy is municipal wastes, and whilst mass burn energy from waste solutions exist, there are many barriers to its implementation. One alternative approach is to pre-sort waste using combinations of mechanical and biological processes (so call MBT processes) so that energy and additional recycling can be recovered, often at scales unattractive for mass burn systems and overcoming some of the barriers inherent with mass burn energy from waste.

This report reviews mechanical biological treatment processes. These typically split the residual waste stream into 3 fractions: a recyclable stream (glass, metals, etc.), a biological stream (for composting or anaerobic digestion), and a fuel stream for energy recovery. There are about 50 such facilities in operation in Europe mainly in Germany, Italy, and Spain. There is considerable interest in these technologies throughout the world, but particularly in Europe, as a means of achieving resource recovery (materials and energy) and landfill diversion. However, while the technology has its limitations and is still developing it offers potential EfW solutions in circumstances where other traditional approaches would be difficult to implement.

Introduction

One of the Topics in the Programme of Work being undertaken by Task 36 in the 2004-2006 triennium is Mechanical Biological Treatment (MBT) of municipal solid waste (MSW). The aim of this work is to review the status of MBT systems and their potential for integrating energy recovery processes.

One of the drivers for this technology in Europe is the Landfill Directive [1]. The Directive imposes targets on EU member states to reduce the amount of biodegradable waste going to landfill compared to the waste generated in 1995 to: 75% by 16 July 2006; 50% by 16 July 2009; and 35% by 16 July 2016. An even stronger driver is the complete ban on organic material entering landfills in countries such as Sweden, Switzerland, Austria, and Germany.

Compliance with the EC and national directives requires increased deployment of recycling and recovery operations for waste. One of the options is to segregate the biodegradable waste and treat it in one of a number of ways. The interest in MBT is increasing as a potential option for achieving the requirements of the landfill directive.

In other parts of the world the key driver is the additional resource efficiency achieved through sorting and treatment to optimise the embedded energy recovery through maintaining the energy contained in materials and products that are recycled, rather than combusted, for the recovery of the inherent energy [2].

The use of MBT also alleviates some of the public antipathy for Energy from Waste (EfW) incineration technologies [3]. MBT allows the recovery of energy from municipal wastes with reduced problems in gaining permits to build such plants.

MBT Process and Products

MBT is a generic term that encompasses a wide range of technologies that aim to process waste by a mixture of biological treatment and mechanical separation to achieve waste stabilisation, recycling and energy recovery. The details of a range of systems are provided in system reviews e.g., those carried out by Juniper [4], UK Environment Agency [5, 6] and the Swedish Association of Waste Management [7]. In MBT the biodegradable fraction is treated post sorting, whilst in Biological Mechanical Treatment (BMT) the biological treatment occurs first.

Mixed residual waste (i.e., waste remaining after source separation, or “grey” waste) is first sorted via a series of mechanical treatment options that separate out recyclable materials (e.g., metal and glass) and fractions for biological treatment and or refuse derived fuel. All systems have sorting processes that separate various fractions and mechanically degrade the organic fractions through shredding, wetting, and tumbling, or through the addition of steam. The main effect is to concentrate these fractions for further processing. The key difference between various systems is the choice adopted for processing the higher calorific value materials. Options include producing a substitute for fossil fuels (refuse derived fuel - RDF), or removing the higher calorific components such as plastics for landfilling and processing the residue to produce compost. The main biological process can be carried out either aerobically (composting) or anaerobically (digestion - AD). Whilst biologically these are different processes, the final degraded solid products are similar, with anaerobic digestion having the added benefit of generating a gas with a high methane content that can be used as a fuel.

BMT is a special case of MBT where the whole of the waste is treated biologically prior to sorting. This biological treatment is principally to dry the waste thus making subsequent mechanical separation for RDF more effective. Waste is aerated within composting vessels; as temperature rises so the moisture is driven off. After one to two weeks the waste is dried and undergoes mechanical separation to generate a fuel (RDF) fraction. The fuel is then prepared for market. The reject waste is still high in organics and can undergo further composting to generate a poor quality compost for landfill cover, but typically this fraction is simply landfilled as the most readily degradable materials are lost in the initial composting stage.

The main outputs from the various MBT/BMT processes are shown in the Table below. The fractions of these outputs vary between the different proprietary processes but generally, depending on the feedstock, are within the ranges shown.

Main Outputs from MBT/BMT Processes	Fractions
Recyclables: e.g., metals aggregate substitutes and plastics	4 - 14%
Organic/Compost: the organic rich fraction that is then composted or digested to generate a compost product and biogas	38 - 70%
Fuel (RDF): the fuel fraction that is either burnt on-site or sent for combustion in a remote combustion facility	0 - 75%
Rejects: the residues and rejects that have to be landfilled.	10 –25%

There are five main types of MBT process:

- Plants which stabilise waste prior to landfill
- Plants which produce a compost product
- Plants which produce a RDF product
- Plants which produce both a compost product and a RDF product
- Plants which incorporate anaerobic digestion to generate biogas for electricity production

MBT processes also enable metals and other materials to be recovered for recycling.

Task 36 has compiled a database of MBT facilities [8]. The number of MBT plants has risen rapidly from around 20 in 1990 to 65 in 2000 and over 170 by 2005. Figure 1 shows the number of plants by country. Germany has the largest number of MBT plants, followed by Italy and Spain. The total capacity of these plants is over 15 million tonnes per year, and the capacities range from under 10,000 tonnes per year to 300,000 tonnes per year.

Typical examples of well established processes are the Horstmann process which produces RDF and compost products and/or stabilised waste for landfilling, and the Eco-Deco process which principally produces a RDF product. The total capacity of Eco-deco plants installed in Italy and Spain is over 750,000 t/yr, and the three plants planned for the UK (two are built) will have a total capacity of over 400,000 t/yr.

An anaerobic digestion (AD) process can be used to recover energy, and one example of this type of process is the 3R-UR process at Eastern Creek, Sydney, Australia which has a current capacity of 175,000 t/yr. An example of a developing technology is the autoclave (steam treatment) process for producing a RDF product which has not been commercially demonstrated for MSW applications but there are several demonstration facilities and projects in planning.

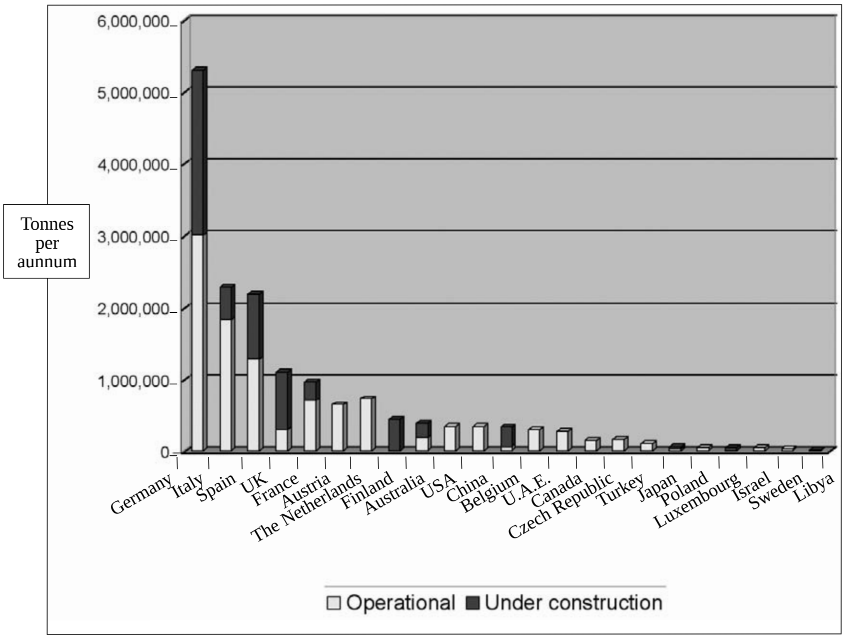

Figure 1: Number of plants in each country
(based on data from the Task 36 MBT database)

The Challenges for MBT

Although a significant number of MBT processes have been developed, and a large number of commercial plants have been constructed, the potential for future plants will depend on a number of commercial and technical challenges, particularly the availability of markets and/or uses for the products that MBT plants produce.

Three approaches for using MBT plants to recover energy are anaerobic digestion, the use of the RDF product as a secondary fuel in an industrial facility, and dedicated combustion facilities.

Anaerobic digestion: AD systems can recover substantial energy from the degradable fractions of the waste and are inherently biological in origin as the plastics and fossil derived wastes do not degrade. The amount of energy that can be derived from the waste is dependant on the feedstock composition and the process configuration. However, depending on the particulars of the process design and operation, gas yields are between 40 and 140 m^3/t of input waste. This corresponds to electrical production of between 100 and 360 kWh/tonne of waste. With plant consumption being between 100 and 300 kWh/t the export energy is between 0 and 200 kWh/t of electricity with additional heat energy available which may find use in heating schemes

RDF as a secondary fuel: The use of RDF in an industrial combustion facility as a replacement for other fuels may be constrained by waste specific legislation (such as the Waste Incineration Directive in the EU). There are also a number of technical issues. For example, RDF has a lower carbon content than coal requiring altered air injection patterns, and the higher levels of alkali metals can result in higher levels of fouling and corrosion. One common use for RDF is in cement kilns, but as the chlorine content can affect the quality of the cement product, the cement industry has set limits for the maximum chlorine content of the RDF product, and some plants have not been able to meet this limit. Furthermore, there is often some public opposition to the use of RDF (and other fuels) as a waste fuel in any combustion facility. The calorific value of RDF varies with processes from products that are similar to the input waste (but are dried or have some inert materials, e.g., glass, metals etc. removed) at 10-12 MJ/kg, to highly refined plastics rich fuels with a CV up to 20 MJ/kg. The efficiency of combustion and energy conversion will vary with the combustion plant with incinerators achieving electric efficiencies of around 20% but co-combustion in power plants will give much higher efficiencies similar to those achieved on the primary fuel.

Dedicated combustion facilities: These can either burn the RDF directly, or further process it using a gasification or pyrolysis technology. The technical issues for direct combustion of RDF will be similar to those for combustion in an industrial facility. Gasification technologies are well established for processing some biomass and waste materials such as wood, but there are currently few commercially operating plants that treat municipal wastes. RDF is more homogeneous than municipal waste as it has gone through mechanical sorting and pre-treatment process, and is easier to process, and there is also a readily available market for the electricity that would be generated. However, the combined costs for the MBT plant and the thermal treatment facility mean that this is likely to be a much less economically attractive option than conventional incineration systems, but still may be more appropriate to a particular location due to the local political, legislative, or structural circumstances. It can also apply to areas where smaller satellite MBT facilities can support a central combustion facility where higher efficiencies can be exploited through larger scale plant, improved technology, or locating near a heat user.

The RDF produced by a MBT process will have to compete with other “renewable” or “non-fossil” fuels such as tyres, biomass products, and energy crops. Potential users may view fuels with a high renewable content as a more attractive fuel, but the RDF produced by many MBT processes will have a high plastic content diluting the renewable content, and thus would complicate the accounting of CO_2 benefits or may not count as a renewable fuel under some regulatory systems.

Research suggests that the RDF produced by steam treatment (autoclave) processes will have a much higher biomass content (the RDF contains a much lower percentage of plastic), and thus this type of process, may be able to produce a more marketable RDF product. It should be noted that these processes are still in development and no full scale processes are operating on MSW and the initial promise of these system may not be fully realised.

The development of markets for these fuels is being assisted by the development of standards for solid recovered fuels (SRF) through the European standards organisation (CEN /TC342). The development of these standards will allow developers and operators to optimise their facilities for the fuel qualities available with the confidence that the fuel will not compromise operation of their energy production plant. However, the existence of standards will not of itself develop markets and other factors will be required to fully facilitate the sale of RDF/SRF.

Where AD is a component of the MBT system then the biogas produced will contribute to the energy balance of the plant. The opportunities for gas utilisation have been extensively addressed by Task 37 and include direct combustion in a boiler, engine, or turbine to generate steam or electricity or conversion to pipeline quality for injection to the gas network or use as vehicle fuel [9].

MBT processes may also produce a compost product from the mixed residual waste input which is likely to have higher levels of contamination (glass, metal, plastics) and lower nutrient levels than products produced from source separated feedstocks. Thus, whilst there may be opportunities to use the compost/digestate produced by MBT processes as a soil improver, it will be very difficult for it to compete with the compost produced from source separated materials in many of the current markets for waste derived compost products. Most of the compost being produced by MBT plants is currently being landfilled or used as landfill cover, although some is being used in Australia, Spain, and Israel. The use of compost from mixed residual waste depends entirely on the legislation implemented in the various countries.

MBT plants can also recover dry recyclable products including ferrous and non-ferrous metals, glass, and a mixed polymer plastics product. These products will have to compete with source separated products, and whilst the glass product may well be suitable for use in aggregate substitute applications, markets for the mixed polymer product are currently limited.

The original concept for MBT was to develop processes that reduce the biodegradable content of residual waste, by stabilising it through the use of a composting process so that it could be landfilled with lower environmental impacts. This approach is supported by environmental pressure groups and a principle benefit of this approach is that the public opposition associated with mass burn systems can be minimised. This allows the development of EfW systems in locations where for example waste heat could be fully utilised and where permitting processes may prevent traditional systems.

In Germany, the first MBT plants which were installed were able to identify markets (cement kilns and power stations) for their RDF product, but the limited total size of these markets, together with the issues regarding potential use of the compost product, mean that the new plants which are being constructed in Germany in order to enable the landfill Directive targets to be met are only producing a stabilised product (with a organic carbon content of less than 5%) which is then landfilled. Recent changes in German legislation have also reduced the capacity in EfW facilities, which means that finding capacity to burn additional RDF will be more difficult. It should be noted that there on-going substantial increases in waste incineration capacity in Germany. Sweden and the Netherlands to cope with waste diverted from landfill.

The Future for MBT

Conventional EfW (incineration) will continue to have a key role to play in treating residual wastes. MBT type processes may complement EfW systems and offer a number of potential benefits but face considerable challenges in realising these. Factors that make MBT attractive include the following:

- MBT plants may be financially viable when the reject fraction can be landfilled and landfill charges are low.
- MBT plants have the potential to operate economically at smaller scale and thus have the ability to process waste locally, producing a RDF product that can be burnt in more remote combustion facilities.
- The RDF product should be more suitable for heat recovery as well as electricity generation as the scale should better match the smaller demands for heat in areas without district heating networks.
- MBT integrated with anaerobic digestion offers the potential for renewable energy recovery compared to composting based systems.

However, a number of factors can make MBT unattractive:

- The overall amount of energy, as electricity, which can be recovered using a MBT process is likely to be lower than that from using conventional incineration. This is due to the energy used in the process and the residues sent to landfill and not burnt.
- Lack of markets for the RDF and compost products can prove a barrier for the commercial viability of the MBT facility. Processes which might produce higher biomass content RDF product (such as autoclaving) are still being developed and may provide some competition for MBT in future.
- The poor public perception of any facility combusting waste derived fuels (including the RDF produced by MBT plants and industrial processes burning the RDF product) can be a barrier for getting permits to operate.
- Greater landfill capacity will be required for process rejects (and for any products which can not be marketed or used).

Some MBT technologies are well established, and whilst markets have been found for the RDF products that the initial plants produced, the current market capacity is limited. A large potential market for RDF is use in power stations, but unless co-firing solutions can be further developed successfully (both commercially and technically), the capacity for using RDF products to generate electricity may well be restricted to either MBT plants which incorporate an AD facility or a dedicated thermal conversion facility. There will be limited opportunities to recover heat at these plants as waste facilities are often sited away from other industry and housing due to concerns over odour and emissions. Additional development work could be conducted to produce better quality compost products and develop suitable markets for them and to improve the quality and range of other recyclates to enhance the conservation of embedded energy. Otherwise, the future role of MBT may well be just to treat small local arisings of waste in order to recover recyclables and stabilise the remaining waste prior to landfill, but this will depend on the availability of suitable landfill capacity.

Task 36 participants visiting the OMRIN MBT plant in the Netherlands. This plant features mechanical sorting and anaerobic digestion as the biological treatment. The residual fraction is partially land filled but mainly incinerated

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News from the Secretariat

The 59th meeting of the Executive Committee was held in Golden, Colorado, USA on 25-27 April, with Kyriakos Maniatis as Chairman and John Tustin as Secretary. The meeting was hosted by DOE/NREL. The Chairman expressed the appreciation of the ExCo to Larry Russo for the excellent meeting and study tour arrangements. Some of the outcomes of the meeting are detailed below.

Changes in the Executive Committee

New Executive Committee Members are: Mr Birger Kerckow, Germany; Mr Sandile Tyatya, South Africa and Mr Paul Grabowski, USA. New Alternate Members are: Ms Birte Mesenburg, Germany and Mr Kazuyuki Takada, Japan.

Election of Second Vice Chairman

To strengthen the succession plan, the ExCo agreed it was desirable to elect a second Vice Chairman for 2007. In a close ballot, Ir. Kees Kwant, the Member for the Netherlands, was elected.

Participation in the Implementing Agreement

The participation of Italy in the Implementing Agreement ceased in December 2006. Korea and Turkey sent observers to ExCo59 and made presentations on their national RD&D programmes.

Mr Nobuyuki Hara, Desk Officer for Bioenergy at IEAHQ (left) with Dr Soon-Chul Park, from the Korean Institute of Energy Research.

Technical Coordinator's Work Programme

Dr Adam Brown, the Technical Coordinator (TC), made a comprehensive presentation of his work programme for 2007. The main focus will be policy related deliverables (35%), Task coordination (20%) and responses to IEAHQ (15%). The TC has already been involved with IEAHQ by providing comments on ETE Briefs and two reports related to 'renewable heating and cooling technologies'. He is keen to develop a more proactive approach with IEAHQ rather than just responding to requests. He will review the scope for improved Task coordination in the Agreement, working closely with the Task Leaders. He said it was important to stay focussed on the goal of producing policy-related deliverables. At present there are US$451,000 of uncommitted funds for the triennium ending December 2009. It will be important to have a very strategic approach on how these funds are applied.

The TC presented a proposal for 'technology reviews'. He said that, given the expert resources available to it, IEA Bioenergy is well placed to deliver an authoritative review of each of the main resource and technology trajectories of bioenergy. They would build on the technology position papers which have already been produced and could be of great value in informing both influential IEAHQ publications and national policies. The reviews could also help to develop an appreciation of the technologies most likely to be able to contribute significantly to sustainable energy supply on a global scale. It was agreed that this was an important multi-year, strategic direction for the Implementing Agreement.

Strategic Publications

The paper 'Potential Contribution of Bioenergy to the World's Future Energy Demand' prepared by Andre Faaij and the Tasks was presented for approval and will now proceed to publication.

The proposal for a paper titled 'Lifecycle Analysis of Biomass Fuels, Power, and Heat as Compared to their Petroleum-based Counterparts and Other Renewables' was approved. Production will be managed by Task 38. The aim is to cover key LCA aspects of bioenergy and to compare the most important bioenergy chains with their fossil and renewable competitors. The final draft will be available by December 2007.

Another strategic proposal - a 'Handbook of Pellet Production and Utilisation' - was also approved. Production will be managed by Task 32. The scope of the handbook will include international pellet markets as well as relevant international constraints and applications.

Energy Technology Essentials

IEA Bioenergy now has the opportunity to publish material in a new four page technical fact sheet series called Energy Technology Essentials (ETE's). Produced by IEAHQ, they are used at IEA Ministerial and other policy-type meetings. They will provide an excellent mechanism for communicating IEA Bioenergy information to the highest levels. At ExCo59, it was agreed that each Task produce an ETE instead of a Task Technology Report as a 'one-time-action'.

ExCo59 Workshop

A very successful workshop titled 'The Biorefinery Concept' was well attended by ExCo Members and Task Leaders. Presentations were:

- Commercialising biorefineries: the path forward - Larry Russo, DOE, USA
- Ensuring success through stage gate and beyond - Bob Wooley, NREL, USA
- Proving biochemical technologies at the pilot scale for integrated biorefinery development - Dan Schell, NREL, USA
- Biorefinery: from agriculture towards industrial applications - Ed de Jong, WUR, The Netherlands
- Developing and proving thermochemical technologies at the pilot scale for integrated biorefinery development – Dave Dayton, NREL, USA
- The IBUS concept: integrated biomass utilisation systems (co-production of electricity and bioethanol) - Børge Holm Christensen, Inbicon A/S, Denmark
- Incorporating conversion R&D and demonstrating for adaptation to an existing facility. Contrast barriers and successes in US versus EU deployment - Quang Nguyen, Abengoa Bioenergy, USA
- Incorporating conversion R&D and demonstrating for adaptation in an existing facility - Michael Ladisch, Aventine Bioenergy, USA

- Upgrading of by-products from biodiesel and the sugar industry by bioconversion and chemical catalysis - Thomas Willke, Federal Agricultural Research Center (FAL), Germany
- Overcoming the challenges of commercialising thermochemical R&D and pilot plant results - Prabhakar Nair, UOP, USA
- From R&D through piloting to commercialization: managing the process - Jim Spaeth, DOE, USA
- Biorefinery Development: the Iogen Story - Maurice Hladik, Iogen Corporation, Canada

The presentations and a summary and conclusions from the Workshop are now available on the IEA Bioenergy website.

ExCo59 Study Tour

NREL

In conjunction with ExCo59, about 35 attendees participated in an excellent study tour organised by Larry Russo and his colleagues at the National Renewable Energy Laboratory (NREL). NREL is the US Department of Energy's main facility for renewable energy research and established the National Bioenergy Center in October 2000. The Centre's technologies are available for industry R&D to foster development of biomass conversion technology and biorefineries. The study tour was of core interest to the participants.

Dr Mike Himmel conducted a tour of the Biomass Surface Characterisation Laboratory (BSCL). Advanced imaging of plant material provides insights into biomass recalcitrance, to help researchers unlock the embedded energy in plants. The philosophy is that by understanding the structural barriers of biomass - especially biomass surfaces - conversion processes can be taken to the next stage. The BSCL has electron and optical microscopes and other research tools, to probe biomass-to-energy processes at atomic and molecular levels. Such highly sensitive instruments must operate in a stringently controlled environment.

DAN SCHAFFER FEDERAL BUILDING
NATIONAL RENEWABLE ENERGY LABORATORY
VISITORS CENTER

The study tour group outside the NREL Visitor Centre in Golden, USA.

Dr Calvin Feik described the Thermochemical Conversion Pilot Facilities to the group. He said they were working on a wide variety of feedstocks, including agricultural residues and energy crops, with the feedstock often being in pelletised form. They also work on feedstocks supplied by industry and carry out parametric testing for individual companies. The Thermochemical Process Development Unit (PDU) can be operated in either gasification or pyrolysis mode. The half-ton-per-day thermochemical PDU is based on a fluidised-bed reactor coupled with a thermal cracker. This configuration is very flexible and can handle a range of process conditions to reflect product gas compositions of interest to industrial partners.

Particulate removal, secondary catalytic conversion, and condensation equipment are also available. The modular design of the facilities allows them to readily accommodate equipment supplied by research partners. Process mass balances are continuously computed from online data. Products and intermediates can be analysed by several methods.

Raw synthesis gas and pyrolysis vapours can be upgraded using the fluidised-bed catalytic reforming reactor. The integration of power generation applications with biomass gasification processes can be evaluated, for example, by testing product gas usage in internal combustion engines or micro-turbines. So can the production of fuels and chemicals in micro-catalytic reactors. These capabilities add up to a unique R&D facility for optimising and integrating thermochemical biomass conversion processes.

Dr Calvin Feik, speaking to the tour group at the NREL Thermochemical Conversion Plant facility.

Dr Rick Elander conducted a tour of the Biochemical Conversion PDU which is the most widely used facility at NREL, as it allows testing and development of complete production processes. It is an integrated pilot plant for converting biomass (e.g., corn stalks and cobs, sawdust and switchgrass) to ethanol at a rate of 900 kg per day of dry biomass and has been operating for 12 years. It was designed to provide a user facility to accelerate the development of processes for the conversion of a wide variety of lignocellulosic biomass types to ethanol. The objective is to perform routine maintenance and calibration activities to maintain the facility in a state of operational readiness for both internal and external customers. Such activity significantly improves the operability of the pilot plant and enhances its capability to supply necessary process performance data for customers. Fermentation trials can be performed with aerobic or anaerobic micro-organisms in batch, fed-batch, or continuous mode. The researchers are working to improve the efficiency and economics of the biochemical conversion process technologies by focusing their efforts on improving pre-treatment technology, breaking hemicellulose down to component sugars, and developing more cost-effective cellulase enzymes for breaking cellulose down to its component sugar.

Coors Brewery

The afternoon of the study tour was spent at Coors Brewery in Golden, the world’s largest brewery on a single site, which was selected for its high quality rocky mountain water. The group was shown all the stages of beer making from steeping (preparing the barley for germination), germination and kilning of the barley; milling, brewing, fermentation and their unique sterile-fill process. There was time to taste the products, but the highlight was a special visit to the recently expanded ethanol plant.

Coors launched the ethanol operation in 1996 with a plant producing 1.6 million gallons of ethanol from brewing wastes which are piped from the brewery. With increasing ethanol demand Coors expanded the plant in 2005. The plant now produces in excess of 4 million gallons per year of 200 proof ethanol. This is accomplished through conventional processes which include: a low temperature cook section; enzymatic conversion of starches to fermentable sugars; yeast fermentation (two 250,000 gallon fermenters); stripping of ethanol from the mash; distillation; and molecular sieve dehydration of the alcohol. Coors produces 87,000 tons per year of brewer's grains on a dry-matter basis from the brewing process. These are currently sold as cattle feed in a wet and dry form.

Merrick, an engineering and architectural company, owns the plant and leases the land from Coors, who operate the facility. Valero Energy Corp. blends the ethanol produced into gasoline for its Diamond Shamrock stations in Colorado.

Participants in the study tour at the Coors Brewery ethanol facility.

Bioenergy in USA

Larry Russo, US Department of Energy, USA

Over the last two years, biomass has taken the spotlight as President Bush has laid out increasingly aggressive goals for moving biofuels into the marketplace, to reduce the nation's dependence on foreign sources of energy and reduce greenhouse gas emissions from the transportation sector. President Bush has established a goal to reduce USA gasoline usage by 20% in the next ten years - called 'Twenty in Ten'. USA will reach this ambitious goal by setting a mandatory fuels standard to increase the supply of renewable and alternative fuels such as ethanol. This standard will require 35 billion gallons (133 billion litres) of renewable and alternative fuels in 2017 which is nearly five times the legislated 2012 target. In 2017, this will displace 15% of projected annual gasoline consumption in USA.

In addition to expanding the use of renewable and alternative fuels, 'Twenty in Ten' also aims to reform and modernise corporate average fuel economy standards for cars and extend the current light truck standard. In 2017, it is estimated that increased fuel efficiency will reduce projected annual gasoline use by up to 8.5 billion gallons (33 billion litres), an additional 5% reduction in gasoline usage. These combined efforts in alternative fuels and fuel efficiency will enable USA to meet the goal to reduce gasoline usage by 20% in the next ten years.

Critical to achieving the 'Twenty in Ten' goal are the Department of Energy (DOE), the National Laboratories and university and industry partners working together. Biomass research has been a cornerstone of DOE's renewable energy research, development and deployment efforts over the last 25 years. Biomass, which includes agricultural and forestry residues, perennial grasses, woody energy crops, and post-consumer wastes, is unique among the renewable energy resources in that it can be converted to carbon-based fuels and chemicals, in addition to electric power.

Meeting these goals will require significant and rapid advancements in biomass feedstock and conversion technologies; availability of large volumes of sustainable biomass feedstock; demonstration and deployment of large-scale integrated biofuels production facilities; and biofuels infrastructure development efforts. In addition, the existing agricultural, forestry, and commercial sectors will be making the decisions to invest in biomass systems - from shifting land use, to building capital-intensive biorefineries, to establishing the infrastructure and public vehicle fleet for ethanol distribution and end use - in the context of economic viability and the needs of the marketplace.

DOE's national laboratory network is comprised of more than a dozen facilities including the National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory, Idaho National Laboratory and Pacific Northwest National Laboratory. These state-of-the-art R&D facilities provide the capability to perform cutting edge research which can be implemented into commercial technology to achieve the USA's aggressive bioenergy goals.

The ambitious USA goal of 'Twenty in Ten' is driving R&D efforts at the DOE to expand the market for biomass fuels. The efforts of the DOE and its laboratories such as NREL are helping to facilitate a more rapid deployment of biofuel technologies.

For more information on 'Twenty in Ten' visit: www.whitehouse.gov/infocus/energy/

For more information on biomass research at NREL, visit: www.nrel.gov/biomass/

Task 33: Thermal Gasification of Biomass

This summary article was supplied by Dr Suresh Babu, Leader of Task 33.

Gas cleanup for biomass gasification

A technical hurdle that almost all gasification processes have to overcome is the development of economical and environmentally sound gas cleanup and effluent recycle and disposal processes. Raw product gases contain particulates, tars, ammonia, alkalis, chlorides and other impurities, which have to be almost completely removed before converting synthesis gas to fuels and chemicals.

In this context, Task 33 organised a workshop in Dresden, Germany to review the developments in raw gas cleanup. The research examples presented at this workshop show significant progress with both low- and high-temperature gas cleaning. The commercial applicability of these developments will evolve as these technologies are demonstrated over extended test periods and upon validation of techno-economic benefits.

Gas cleanup research in USA

Both conventional and advanced gas cleanup options are being pursued to remove tar, particulates and alkali metals from raw product gases. In addition to these contaminants, light hydrocarbons should be minimised or eliminated to avoid the energy-intensive reforming process and reduce the overall process costs. The ultimate objective of tar reformer research at NREL in Golden, Colorado is to reduce the cost of synthesis gas production. In support of this objective, NREL is testing and evaluating catalytic steam reforming of tars produced during gasification of biorefinery residues.

The Gas Technology Institute in Des Plaines, Illinois is using high temperature glass melting technology to produce Olivine containing catalysts for in-situ removal of tars in biomass gasification. These tests, conducted over a range of 750-900°C, showed that 80% of naphthalene was decomposed at the lower temperature and near complete conversion was observed at 900°C.

The Research Triangle Institute in North Carolina and its research partners developed a fluidised bed reactor containing a novel tri-functional catalyst that decomposes tar and remove NH_3 and sulphur compounds from raw synthesis gas over a temperature range of 600-700°C.

Gas cleanup research in Austria

The Technical University of Vienna, Austria has conducted research on the comparative evaluation of tar removal using Olivine versus Nickel-Olivine. Using the FICFB demonstration gasifier at Güssing, it has been determined that Ni-Olivine reduces tar content by about 90%. Further investigations are in progress to ascertain the effect of Ni-Olivine on the distribution and nature of tar components. Tests with a commercial monolithic Ni honeycomb catalyst installed in a slip-stream at the Güssing gasification plant, show that it is possible to achieve >99% removal of most of the major tar related contaminants under raw gas conditions.

Ultra-clean gas cleanup research in Germany

ITC in Karlsruhe has been conducting an exhaustive screening of sorbents for removing trace constituents of HCl and H_2S from hot raw gases, in support of commercialising the Sustec SVZ process for biofuels. The entrained high-temperature gas cleaning process at 800°C does not produce any tars. Furthermore, the use of sorbents essentially removes all HCl and H_2S and most of the organic sulphur.

High-temperature gas cleanup research in UK

Porvair in Norfolk is investigating using catalytically active metal foam in biomass gasification research. Metal foam is a promising substrate for gas cleanup, with a high catalytic surface area, low pressure drop, and good depth filtration properties. Porvair's permeable media filters are made to withstand 900°C. They have a porosity in the range of 3.1 x 10-11 m^2 to 1.8 x 10-13 m^2 which exhibits an efficiency of 99.98% separation of particles > 0.3 micron, and 95% separation of < 0.45 micron particles.

Gas cleanup research in The Netherlands

Dahlman is commercialising OLGA, a multistage oil-based tar scrubbing system which operates above the water dew point. Pilot tests have shown that the process removes all tars and tar aerosols, as well as most of the BTX compounds. The process is currently being tested with an updraft gasifier in Moissannes, France.

The Technical University of Eindhoven is exploring the use of pulsed corona to decompose tar molecules under hot-gas conditions. Pulsed corona is an efficient source of electrons, radicals, and excited molecules. When energetic electrons collide with gas molecules they produce radicals which are chemically very active and easily attach to or modify other molecules that they come in contact with. In general, it has been observed that higher corona densities are required under reducing conditions compared to inert gas conditions.

Gas cleanup research in Finland

VTT in Espoo has conducted extensive slip-stream gas clean-up tests with nickel monolith. Reporting on the gas cleanup research at the Novel gasification plant in Kokemaki, VTT reported that the gas cleaning system works adequately to provide a clean fuel gas for the downstream Jenbacher gas engines. The treated gas contains tars < 100 mg/Nm^3, ammonia < 50 ppmv after catalytic removal and scrubber, and dust < 10 mg/Nm^3 after gas filtration.

Gas cleanup research in Switzerland

The Pyroforce® Gasification system demonstrated in Switzerland first cools the raw gas to approximately 160°C to prevent clogging by tar/soot. The cooled gas is passed through pre-coated filters to remove solids, acids, heavy metals and sticky tars. It is then cooled further in washing columns, to condense water along with heavy HC and partial absorption of ammonia. With this methodology the biomass gasifier and the gas engine have demonstrated satisfactory integrated operation over extended periods

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UPDATE 35

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Biomass Gasification for Hydrogen Production – Process Description and Research Needs

This Technology Report from Task 33 was prepared by the Task Leader Suresh Babu for ExCo56 in Dublin in October 2005.

Introduction

Renewable biomass and biomass-derived fuels could be readily gasified to produce high purity hydrogen or hydrogen-rich gas. Among the biomass energy conversion schemes, gasification produces a product gas, which could be used either to produce hydrogen or co-produce value-added by-products. As a readily renewable fuel, biomass may become a significant component in the global sustainable energy mix if the use of fossil fuels is limited for any number of reasons. In addition, biomass utilisation can expedite mitigation of greenhouse gas emissions and promote introduction of 'green' industries with associated growth in rural economies. Hydrogen or hydrogen-rich gas produced from biomass could be readily used in most of the present natural gas or petroleum derived hydrogen energy conversion systems and also in advanced power generation devices such as fuel cells.

Process Descriptions

At present, there are no commercial biomass gasification processes for hydrogen production. In general, except for direct air-blown gasification, enriched-air or oxygen-blown gasification, steam gasification, or any other indirectly heated gasification process should be able to produce a synthesis gas, which could be converted to hydrogen. From the wide variety of biomass gasification processes that are being developed, processes considered to be suitable for producing either hydrogen or hydrogen-rich gases are described in the following sections.

BIOSYN Gasification and Gas Conditioning Technologies: The BIOSYN gasification process [1] (Figure 1) was developed during the 1980s by BIOSYN Inc., a subsidiary of Nouveler Inc., a division of Hydro-Quebec (Montréal, Quebec, Canada). The process is based on a bubbling fluidised bed gasifier containing a bed of silica or alumina capable of operating up to 1.6 MPa. Extensive oxygen-blown biomass gasification tests were conducted during 1984 to 1988, in a 10 tonnes/hour (t/h) demonstration plant located at St-Juste de Bretennieres, Québec, Canada, to produce synthesis gas for methanol production. Air blown atmospheric gasification tests were also conducted for evaluating cogeneration. In the following years, a 50 kg/h BIOSYN process development unit has also proven the feasibility of gasifying primary sludges, RDF, rubber residues (containing 5 - 15% Kevlar), and granulated polyethylene and propylene residues to produce hydrogen-rich synthesis gases.

The process accepts feed particle sizes up to 5 cm, feed bulk densities higher than 0.2 kg/l and feed moisture content up to 20%. The thermal efficiency for biomass gasification varies from 70 to 80%. The product gas containing mostly CO, CO_2, and H_2 could be cleaned to remove carry over dust and condensable tar and upgraded to produce high-purity hydrogen. With air as the gasifying agent the HHV of the fuel gas is about 6 MJ/Nm^3. Enriched air, with

40% oxygen, can produce a fuel gas having a higher heating value (HHV) of about 12 MJ/Nm^3 at half the gas yield. The raw gas cyclones remove 85 to 95% of entrained particles.

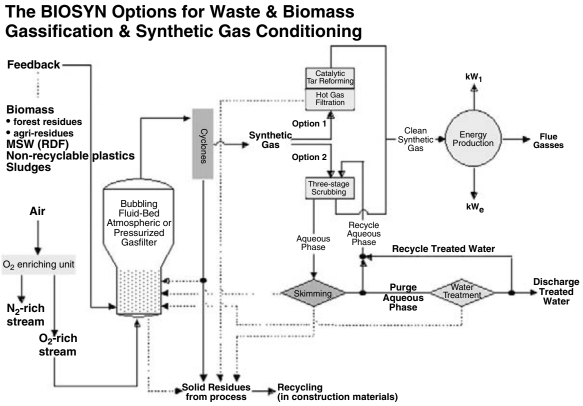

Figure 1: BIOSYN Process

The supporting R&D conducted during the demonstration of the BIOSYN Process, includes gas scrubbing for efficient tar removal with reduced water requirements, recycling the insoluble tars to the gasifier, wet oxidation and adsorption of dissolved organic compounds in the scrubbing water, and recycling carbon-rich ashes and carry over carbon with adsorbed organic compounds to the gasifier. The R&D effort also included hot-gas filtration of entrained dust using a static bed of perlite particles and a moving sand bed filter, and catalytic steam cracking of tar. Proprietary gas clean-up catalysts were developed to decompose 99% of tars and 97% of naphthalene compounds. The fully integrated BIOSYN Process, with hot-gas filtration and high-temperature tar reforming, water-gas shift conversion to convert CO to hydrogen and CO_2, and CO_2 removal to produce high-purity hydrogen, was never demonstrated. The BIOSYN Process is now commercialised by Enerkem Technologies Inc, a subsidiary of the Kemestrie Group, a spin-off company of the University of Sherbrooke. Recently, a commercial installation to gasify 2.2 t/h of granulated polypropylene residues was planned for construction in Spain. Environmental International Engineering S.L., a Spanish-based development and engineering group, in partnership with Enerkem, was planning to erect and commission the plant. The electricity output of the plant will be sold to the grid.

FERCO SilvaGas Process: The FERCO SilvaGas Process [2] (Figure 2) employs the low-pressure Battelle (Columbus) gasification process which consists of two physically separate reactors; a gasification reactor in which the biomass is converted into a medium calorific value (MCV) gas and residual char at a temperature of 850 to 1000ºC, and a combustor that burns the residual char to provide heat for gasification. Heat transfer between reactors is accomplished by circulating sand between the gasifier and combustor. Since the gasification reactions are supported by indirect heating, the primary product is a synthesis gas with medium calorific value. A typical product gas composition obtained in pilot plant tests, at steam to biomass (wood chips) ratio of 0.45, is 21.2% H_2, 43.2% CO, 13.5% CO_2, 15.8% CH_4, and 5.5% C_2+. The estimated HHV of this fuel gas is 17.75 MJ/Nm^3. A 200 tonnes/day (t/d) capacity Battelle demonstration gasification plant was built at the McNeil Power plant in Burlington, Vermont. Following plant shakedown and initial tests the plant has operated intermittently. At this plant, the fuel gas was co-fired in the existing McNeil wood fired boiler. The process was developed by US DOE Biomass Power Program, FERCO, Battelle Columbus Laboratory, Burlington Electric Department, Zurn Industries, OEC/Zurn, and NREL.

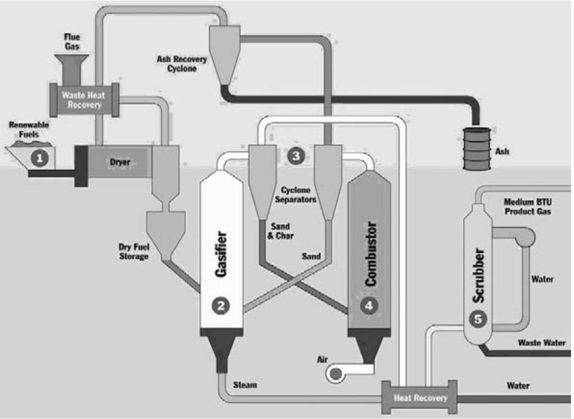

Figure 2: SilvaGas Process

MTCI Process: The MTCI gasification process (Figure 3) also employs indirect heating to promote steam gasification of biomass to produce a MCV fuel gas. The gasifier combusts part of the fuel gas in pulsed combustion burners which promote heat transfer to the gasification section. Extensive pilot plant tests were conducted in a 20 t/d process development unit (PDU) at the MTCI laboratories near Baltimore, Maryland. These tests also included evaluation of black liquor gasification process. Based on the PDU tests a 50 t/d capacity black liquor gasification demonstration unit was built at Weyerhauser's New Bern facility.

In the MTCI Process, the black liquor is steam reformed/gasified at an operating temperature of about 600ºC (~1,110ºF). The raw gas is upgraded through several steps of gas cleanup, resulting in a synthesis gas rich in hydrogen (>65% by volume) with a higher heating value (HHV) of approximately 10.4 MJ/(dry)Nm^3. In one of the pilot test campaigns, cleaned synthesis gas was metered to a solid-oxide fuel cell operating at about 1000ºC (1830ºF), which produced a net 2.6 volts D.C., 62 amps or an equivalent of 161 watts of electricity.

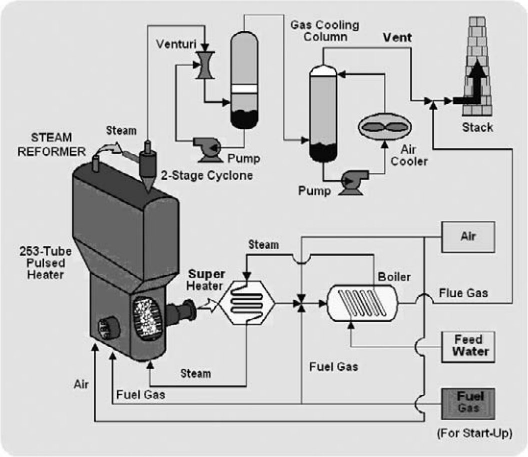

Figure 3: MTCI Process

The first MTCI black liquor gasification plant was commissioned in September 2003, at the Norampac mill in Trenton, Ontario, Canada. The plant was designed to handle 115 t/d back liquor (60% solids). The gasifier has operated for extended periods, but has experienced some bed agglomeration problems. The second MTCI plant, with a capacity of 200 t/d sodium carbonate black liquor (with 60% solids), was launched in 2001 by Georgia Pacific, Fluor Daniels, and Stone Chem, with support from USDOE. The five-year demonstration project is located at the Georgia Pacific paper mill in Big Island, Virginia. The project will cost approximately $87 million with about 50% cost contribution from industry. Plant commissioning was started in the fall of 2004, and to date the unit has operated at 50% of design capacity. No agglomeration problems were observed at this demonstration plant.

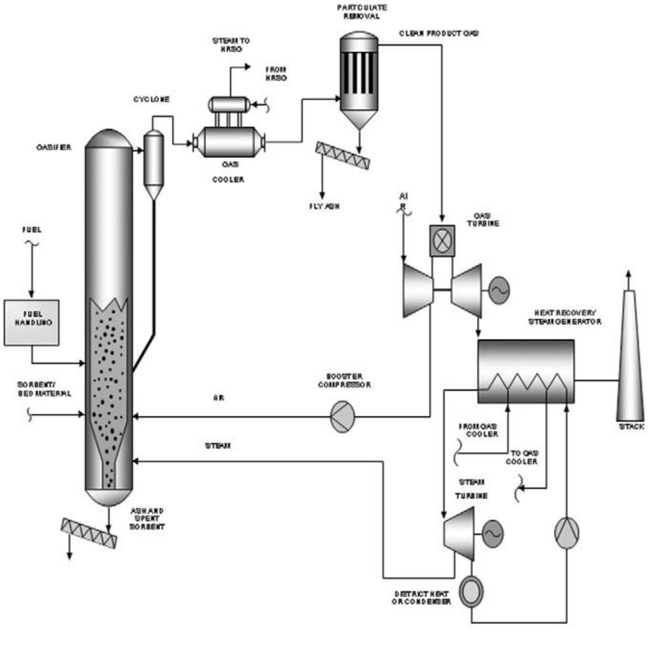

Figure 4: RENUGAS Process

RENUGAS Process: The GTI/IGT RENUGAS®, Process [4] (Figure 4) employs a 20 bar pressurised bubbling fluidised bed. The process was extensively tested with a variety of biomass materials, including bark-paper sludge mixtures, bagasse, and pelletised alfalfa stems in a 12 t/d PDU at IGT test facilities in Chicago. Subsequently USDOE selected the RENUGAS Process for scale-up and demonstration, using bagasse, at the HC&S sugar mill at Paia in Hawaii. The project was terminated when the 100 t/d demonstration plant had limited success in handling the low-density, shredded bagasse. A typical gas composition obtained in the IGT PDU with bagasse at 2.2 MPa, and 850ºC is 19% H2, 26% CO, 37% CO_2, 17% CH_4, and 1% C2+. The heating value of this fuel gas is approximately 13 MJ/Nm^3. The project participants included US DOE Biomass Power Program, IGT, Westinghouse Electric Corporation, State of Hawaii, PICHTR, and HC&S.

Although, the pressurised air-blown RENUGAS process was initially developed for IGCC applications, by replacing air with oxygen, the process could produce synthesis gas that could be upgraded to high-purity hydrogen.

Carbona, which licensed the Renugas technology from GTI, has constructed and tested a 15 MWth high-pressure (20 bar) Renugas pilot plant in Tampere, Finland [5]. Around 1993, Carbona successfully operated the pressurised gasifier for over 2000 hours with a variety of biomass wastes and has also evaluated hot-gas filtration for IGCC application. In October 2004, Carbona reported that ground has been broken for building a 5.4 MWe capacity low pressure, Renugas demonstration project in Skive, Denmark. The project will start its operation with pelletised wood.

In January 2005, GTI completed the shakedown of a new 24 t/d, adiabatic Flex Fuel Test Facility in Des Plaines, Illinois [5]. This facility is capable of gasifying up to 30 t/d of biomass and at operating pressures up to 25 bar.

Forced Internal Circulation Fluidised Bed (FICFB) Process: The two-stage, combined fluidised bed gasifier and CFB combustion process developed by the Technical University of Vienna (TUV), Austria (Figure 5) with Repotec has demonstrated exceptional rapidity of success in scaling-up the laboratory scale unit to a commercial demonstration plant Güssing, Burgenland [6]. The principal novelty of the process is its ability to produce a MCV fuel gas without the use of oxygen. The process employs a catalytically active circulating fluidised bed of solids that can reduce tar in the raw gases. The raw product gases are cooled for heat recovery and scrubbed with an organic liquid to remove most of the tar. The raw MCV product gas can be processed to produce hydrogen or hydrogen-rich gas. The condensate along with some of the scrubber solvent is recycled to the combustion zone for complete thermal decomposition of all condensable organic compounds produced during biomass gasification. The clean gas is then introduced to an Jenbacher gas engine to generate a gross ~2.0 MWe power and ~4.5 MWth heat. The reported parasitic power consumption is ~0.2 MWe. The electrical efficiency of the Jenbacher gas engine is 36 to 37%. At the end of 2004, the gasifier had logged more than 14,000 hours and the total operating time with the integrated gasifier and gas engine was about 11,000 hours.

A typical dry, raw gas composition reported from air-blown biomass gasification tests is given below in % by volume: H_2= 30-45, CO= 20-30, CO_2= 15-25, CH_4 = 8-12 vol.%, N_2=1-5, (NH_3= 500-1000 ppm, H_2S = 20-50 ppm, Tar= 0.5-1.5 g/Nm^3, Particles= 10-20 g/Nm^3).

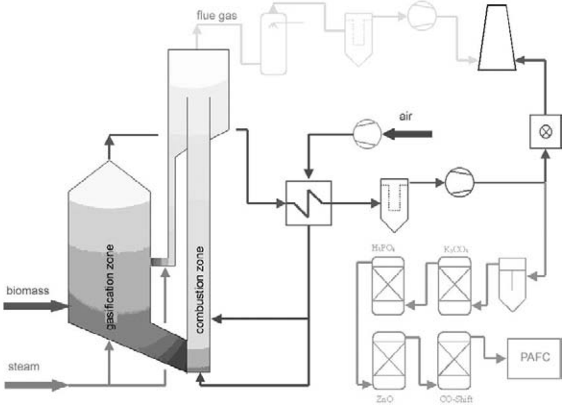

Figure 5: FICFB Gasification Process

CHEMREC Process: In 1987, the development of the Chemrec Process (Figure 6) for black liquor gasification was started in Sweden [7,8]. The process was bought by Kvaerner in 1990. In 2000 Kvaerner sold their majority rights to the German industrial group Babcock Borsig Power (52%) and to the Swedish company Nykomb Synergetics (24%). Since 2002, Chemrec has been in search of seeking new industrial partners because Babcock Borsig Power is in insolvency and its part in Chemrec has been bought by Nykomb Synergetics.

The Chemrec process can be operated at slightly above atmospheric pressure for incremental black liquor gasification in parallel with an existing recovery boiler. The process when operated under pressurised system can replace the recovery boiler. The pressurised black liquor gasification combined cycle mode (BLGCC) is more energy efficient than the recovery boiler and can generate approximately double the amount of electric power than a modern recovery boiler. The Chemrec gasification reactor is similar to the Texaco gasifier (now owned by GE). Black liquor is injected with oxygen, into a high-pressure (~30 bar) and high temperature (~950ºC) reactor to gasify the cellulose, lignin components and smelt and reduce the inorganic salts. The favourable reaction kinetics in the gasifier due to the presence of a catalyst (Na and K) results in low methane content gas compared to normal gasification of biomass. In the low-pressure Chemrec process, black liquor is gasified with air. Atomisation and droplet size are very important to gasifier performance; atomisation is achieved using medium pressure steam. The high-pressure Chemrec process is operated with oxygen. The black liquor injection nozzles are designed to facilitate on-line cleaning. The reactor temperature is maintained at about 950ºC in the lower part of the gasifier. An oil or gas fired burner at the top of gasifier is used to heat the gasifier for start-up and for hot stand-by. The chemical smelt is recovered from the gas stream at the base of the gasifier by quenching with condensate. The product green liquor is pumped to the mill system. A small quantity (a few percent) of sulphur, as H_2S, leaves with the product gas in the low-pressure system while approx 60% of sulphur leaves with the product gas in the high-pressure system. In the pressurised system, the H_2S is removed by scrubbing employing standard H_2S/COS removal technology. By proper selection of the desulphurisation scrubbing process, the absorption of CO_2 can be reduced. With air gasification, the product is an LCV gas, while pressurised oxygen blown gasification results in a MCV gas.

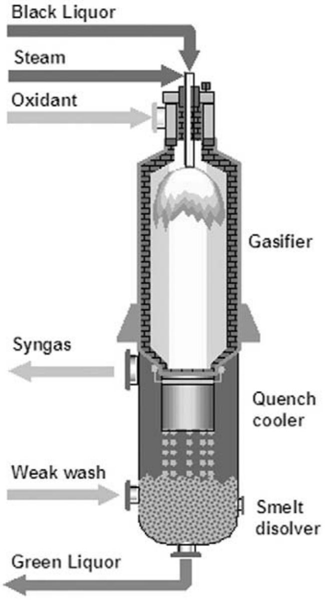

Figure 6: The Chemrec Process

Chemrec has provided the following data on gasifier performance, for the low and high pressure (30 bar) gasification cases. The gas compositions are from two slightly different black liquor feed stocks.

The Swedish Government is providing $25 million (50% matching funds) to develop and verify the performance of the Chemrec pressurised process in two steps. Chemrec has constructed a 20 t/d dry solids (3 MWth), oxygen-blown development plant in Piteå, Sweden. After about one year of testing the process will be scaled up to a 300 t/d dry solids capacity and built as a complete BLGCC plant. The Kappa

Table 1: Gasifier Performance Predictions for Operation with Air and Oxygen

	Low Pressure Air Blown	**High Pressure Oxygen-blown**
Assumptions:		
Reactor Temp, °C	950	950
Reactor Pressure, bar	2	30
Air feed, t/tds	2.2	
O_2 feed, t/tds	—-	0.34
Oxidant temp, °C	100	135
Gas Composition (vol. %):		
CH_4	0.2	1.1
CO	6.0	29.5
CO_2	12.5	14.6
COS	-	0.04
H_2	8.6	31.1
H_2O	26.3	22.2
H_2S	0.2	1.5
NH_3	0.01	0.00
N_2 + Ar	46.2	0.18
Higher heating value:		
(MJ/m^3, dry, at 15^{o}C)	2.6	10

Typical black liquor properties are: C 37.2%, H 3.6%, O 34.4%, S 3.7%, N 0, Na 18.6%, K 2.5%, HHV: 14.36 MJ/kg, dry

Kraftliner mill in Piteå has expressed a desire to provide the host site for the plant. This effort, which began in 2001, will continue through 2006. Upon successful operation in the 20 t/d development plant, US pulp and paper industry and US DOE may consider building a commercial BLGCC demonstration based on the Chemrec technology in USA .

As shown, the gas composition from the pressurised Chemrec process is well suited for further treatment to produce synthesis gas which then can be converted into automotive fuels such as methanol, DME, FTD or hydrogen.

The operation of a 300 t/d dry solids capacity, low-pressure Chemrec gasifier in New Bern (Weyerhaeuser Mill) was started in 1996 and stopped in January 2000 when a crack was detected in the reactor vessel. The plant was taken out of operation and extensive investigations were carried out to understand and come up with a new design to avoid further structural problems. The plant construction was modified and the Weyerhaeuser gasifier has resumed operation in 2003. The new gasifier refractory is expected to last for about two years while the previous lining operated satisfactorily for a little over one year.

SVZ Schwarze Pumpe GmbH: SVZ [9] has converted some of the existing former East German era, FDV Process coal gasifiers in Schwarze Pumpe, Germany to convert biomass, coals, and wastes into clean fuel gas and synthesis gas (Figures 7a, 7b, 7c). The plant gasifies a wide variety of waste materials along with low-rank coals in an updraft moving bed gasifier. The waste materials include demolition wood, used plastics, sewage sludge, auto-fluff MSW, contaminated waste oil, paint and varnish sludge, mixed solvents, tars, and on-site process waste streams. The waste materials are blended with coal at a ratio of 4:1. SVZ has developed an effective feed handling system which employs thermal pre-treatment to convert heterogeneous feed materials to produce a nearly uniform in shape and bulk density gasifier feedstock.

The oxygen-blown, 25 bar-pressurised, 14 t/h FDV process, similar to Lurgi's moving bed coal gasification process, converts the mixed feedstocks to MCV fuel gas or synthesis gas. The raw gas is subjected to conventional (Rectisol) gas cleaning to separate contaminants from the product gas.

The SVZ facility has also built a 25 bar pressurised, 35 t/h capacity British Gas Slagging Lurgi gasification system for converting mixed feed stocks to MCV fuel gas or synthesis gas. As is the case with the FDV Process, the raw gas is subjected to conventional gas cleaning to produce a clean product gas and liquid and solids containing waste slurry stream.

The third oxygen-blown, refractory lined gasifier is the FSV 15 t/h entrained flow gasifier, similar to the TEXACO process, which serves the role of a 'bottoming' gasifier that effectively treats the hydrocarbons containing waste streams from gas processing into a contaminant-free synthesis gas and mineral slag. If required, a supplementary fuel, i.e. natural gas is used to maintain the reactor temperature in the range of 1600 to 1800ºC. This process is today owned by Lurgi and called the Multi Purpose Gasifier.

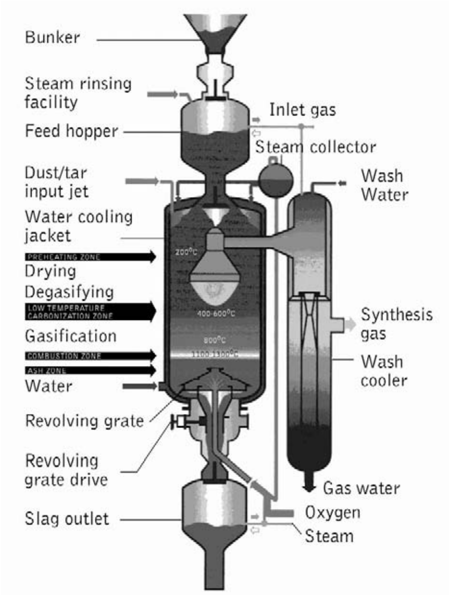

Figure 7A: Pressurised Moving Bed Gasifier with Revolving Grate

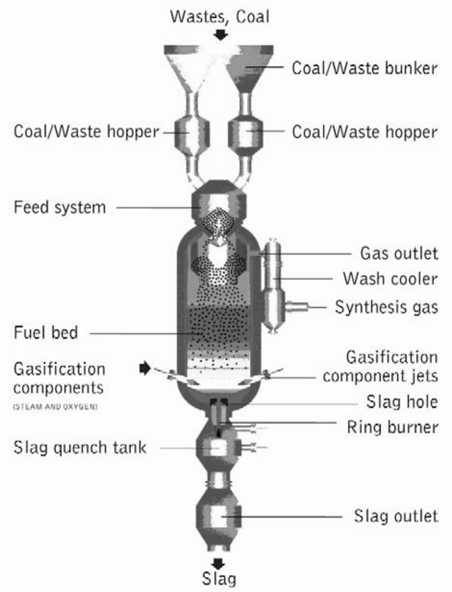

Figure 7B: Pressurised Moving Bed Gasifier with Liquid Slag Discharge

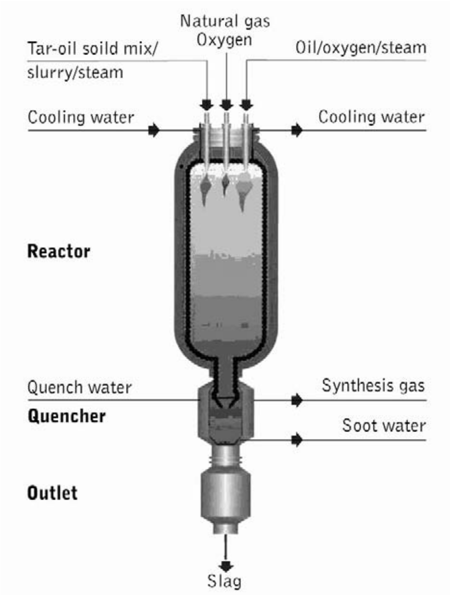

Figure 7C: SVZ Schwarze Pumpe Entrained Flow Gasifier with Slag Discharge

The SVZ plant is a first-of-a-kind integrated gasification, methanol and combined-cycle electricity production plant that converts contaminated and difficult to handle waste materials to clean, value-added products. The high gasification temperatures of up to 1800°C are high enough to totally decompose contaminants in the product gas or gas scrubbing effluent streams. The vitrified slag, the only gasifier waste product, safely encapsulates any residual pollutants and can be used as construction material.

In July 2002, SVZ was sold to ORESTO, a subsidiary of Nord GB Gesellschaft für Beteiligungen mbH, Hamburg.

CHRISGAS Project: Between 1993 and 1999, Sydkraft Ab adopted the Ahlstrom/FW CFB gasification process to develop and demonstrate the first pressurised Bioflow biomass gasification IGCC process for CHP (9 MWth and 6 MWe) application in Värnamo, Sweden [7]. This demonstration, widely recognised for its technical success, operated the pressurised CFB gasifier for about 8500 hours. The integrated operation of the pressurised gasifier with hot-gas clean-up and power generation in a close-coupled Alstom's (now part of Siemens) Typhoon gas turbine was demonstrated for over 3600 hours. Although, the facility has been mothballed for several years, it will be reactivated as the centre piece for demonstrating the CHRISGAS project, a multi-national consortia technology development effort. The project's mission is to develop pressurised, oxygen-blown gasification of biomass and wastes to produce synthesis gas and its subsequent conversion to transportation liquid fuels.[9] The results from the CHRISGAS project should be also useful for evaluating the production of hydrogen from biomass.

The CHRISGAS project is coordinated by Växjö University at the Växjö Värnamo Biomass Gasification Centre (VVBGC). The Project team includes, AGA-Linde, Catator, KS Ducente, Royal Institute of Technology (KTH), S.E.P. Scandinavian Energy Project, TPS Termiska Processer, (Valutec),Växjö Energi, TK Energi, DK, Valutec, FI, FZ Jülich, DE, Linde, Pall Schumacher, University of Bologna, IT, Technical University Delft, NL, and CIEMAT, ES. The project budget is more than Euro18 million.

Research Needs

The following sections highlight research needs for developing and commercialising biomass gasifiers for hydrogen production.

Feed Preparation

Unlike fossil fuels, biomass is dispersed and lacks the infrastructure to ensure sustained supply of low-cost quality controlled gasification feedstock. Biomass has certain physical characteristics, such as low bulk density and its fibrous nature that presents many challenges in collection and transportation to a central gasification plant. Although the feed preparation and feed handling systems for woody biomass are well developed for low-pressure systems, reliable feeders for other types of biomass for pressurised gasifiers require further development.

Low-cost pelletisation of low-density herbaceous feedstocks would widen the range of renewable feed materials that are available for biomass gasification. Pellets are easy and economical to transport and their relatively uniform shape and bulk density would render them easy to handle, store and feed pressurised systems.

Biomass Gasification

The present gasification systems are generally designed and operated to produce fuel gas for heat and power. The processes described above also produce a fuel gas with little or no inert N_2, i.e., produce a synthesis gas containing primarily CO, H_2, CO_2, $H_2O(g)$, and some gaseous hydrocarbons and condensable hydrocarbons. Fundamental research is needed to improve product selectivity, to produce essentially high-purity H_2. The role of catalytic and non-catalytic bed additives on raw product gas yield and thermodynamic limitations should be investigated. Nearly total carbon conversion to produce high-purity H_2 would require minimal gas cleaning and separation to produce pure H_2. It is conceivable that direct-H_2 yield could be improved by varying certain aspects of gasification reactor designs and operating conditions. Gasification reactors should also be designed to incorporate the capability to thermally decompose organic condensates and ammonia that would be produced from systems employing conventional low-temperature gas cleaning and quenching.

Robust and sturdy low-cost, high-temperature heat transfer materials, which can operate up to 1100ºC (~2000ºF) would help develop indirectly heated reactor designs that would prevent products of combustion from contaminating steam or ‘recycled product gas.’

Small-scale, low-cost air enrichment is another technology that will be beneficial to produce hydrogen production from biomass.

Raw Gas Handling and Clean-up

Significant progress has been made over the past 10 years towards developing a better understanding of biomass gas handling and conditioning processes and technologies for use in biomass gasification for advanced power production. However, there is need for further R&D in this process step for removal or elimination of particulates (from attrition of gasifier solids and secondary vapour-phase carbonaceous materials), alkali compounds, tar, chlorides, and ammonia. High-temperature gas processing, including reforming of hydrocarbons and water-gas shift to convert CO to H_2 should be investigated, particularly for raw product gases with all its contaminants produced in biomass gasification. In order to improve the overall thermal efficiency and to retain process simplicity, it is desirable to conduct gas cleaning at raw gas temperatures or at temperatures which may require some gas cooling but does not require any reheating of raw cleaning gases. Gas cooling and design of appropriate heat exchangers have become the focus of the recent Essent/AMER and ARBRE biomass gasification demonstration projects, for co-firing and power generation applications. In the development of high-efficiency gasification systems, it may be necessary that most if not all of these gas handling and gas clean-up R&D should be conducted at elevated pressures that match with the end-use for product H_2.

Gas cleaning R&D should also investigate CO_2 removal at high temperatures, although it may not be required for biomass gasifiers that may be developed for molten carbonate fuel cells. Physical and ionic separation membranes that can separate H_2 at high temperatures would be useful to produce high-purity H_2, while CO or gaseous hydrocarbons are being chemically converted to H_2.

Gas cleaning in general will have a major impact on the environmental impact of biomass gasifiers. Incomplete gas cleaning would shift the contaminant removal problem to some other location downstream from the gasifier, requiring expensive treatment of all process effluents.

Interface Issues and System Integration

As is the case with other energy conversion schemes, there could be several unique issues that need to be addressed for integrating hydrogen producing biomass gasification systems with selected end use applications. Obviously a central hydrogen producing biomass gasifier or gasifiers feeding to a central hydrogen storage and distribution system may face simpler problems compared to hydrogen producing biomass gasifiers that are closely coupled to selected chemical or energy conversion systems. Examples of the latter include issues related to coupling gasifiers with high-temperature fuel cells.

System Definition and Market Assessment

Whenever 'biomass gasification to hydrogen' becomes commercial, it would be necessary to determine the range of capacity of conceptual commercial plants. These specifications would be dependent to a great extent on the application, the cost and availability of feedstock. Upon defining the basic plant specifications, it would be possible to determine the process economics, their advantage over conventional alternatives, and hence the market potential for biomass gasifiers for specific applications.

Information Dissemination and Policy

To promote the successful development and commercialisation of biomass gasifiers for hydrogen production and utilisation, timely dissemination of information is absolutely essential. Given the competition from conventional sources of hydrogen, public education and information are definitely required to craft, deploy, and implement policies that are conducive to commercialising hydrogen producing biomass gasification systems. It is crucial to document the performance of the new biomass gasification systems, to highlight success stories but also in showing solutions to problems that may arise. The deployment of hydrogen producing biomass gasification systems for high-efficiency and selected value-added applications will benefit from policies that encourage the use of renewable fuels.

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